ICKEPS 2012 Challenge Domain:
Planning Ship Operations on Petroleum Platforms and Ports

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Abstract

After the discovery of a promising massive oilfield beneath 2000 to 3000 meters of water in the coast in 2007, Brazilian government has been investing in advanced technologies and infrastructure on deep water extraction of oil and natural gas. New discoveries in what is called pre-salt brought even more challenges in deep water exploitation as well as in several underlined engineering problems to make this work secure, profitable and unharmful to the nature (which is a great concern for Petrobras). One of this problem is connected with the use of ports which are already very crowded, as well as the need to keep vessels of all kind and size near to the shore to further use. That originates a partnership between Petrobras-Transpetro, Design Lab-USP, IAAA-FEI to specify this problem to ICKEPS which also brings another challenge: to use planning (and scheduling in the future) to overcome large and complex optimization problems which would require more time and resources to be solved.

Introduction

Since the 80's there is a recurrent discussion about the relationship between AI (planning) and optimization problems, specially because of the different nature of planning, which is satisfaction oriented, while optimization - when possible - directs to a point that maximize (or minimize) some objective function. Such discussion is even more interesting when concerned with discrete systems such as most transportation and work-flow problems. Besides of that, those problems also have a deterministic capacity as a main constraint.

A stronger version of this discussion reappear at the beginning of this century starting with the analysis of the state space nature of planning since the old STRIPS approach (Kautz and Walser, 1999; Kautz and Walser, 2000) to more recent treatments that emphasize the use of graphs (Bonet and

Geffener, 2001; Nguyen et al, 2002) and also Petri Nets. This is also a challenge to be faced by new tools presented in ICKEPS: to use the state-space approach to deduce important facts and heuristics that could improve the process of planning by the traditional planning tools.

The problem presented here were proposed by Petrobras (the Brazilian Petroleum Company, one of the top five in the world) and has the characteristic of getting in the same problem some of the features that could benefit the state-space approach. The problem depends on deterministic capacity of vessels as a basic constraint, it has multiple and coupled objectives, including routing optimization, and it requires flexibility, which would not be provided by a specific optimization approach. Thus, it is a realistic problem that has constraints to reinforce security and sustainability.

A joint team was created to transform the real problem into this proposal, which does not have real data - which does not change or reduce the challenge - and keep the focus on the relevant aspects, which will let an analysis of state-space or other approaches focused on a problem with the characteristic outlined above.

Generically, the problem can be described as the need to provide transportation of goods and tools from two ports in the land located 200km from each other to platforms in the ocean located in strips from 100km to 300km of distance from these ports. We divided these strips in two parts and we will call them Rio de Janeiro and Santos respectively. Each one would be defined in sectors denoted approximately as shown in the Fig. 1.

Of course the real problem should consider geodesic coordinates, taking into account the earth curvature. Since this is not a detail that impacts the planning treatment it was simply neglected in this proposal. That would add only algebraic transformations and it not linked to the knowledge engineering which is the focus for the competitors.

For simplicity, it was chosen to put six platforms in the Rio de Janeiro strip and only four in the Santos strips. The respective radial distances to the port of Rio de Janeiro is given in Table 1. We also have five vessels, that is, large boats that could transport several tons of cargo. What really makes the difference for the problem is that it takes some time to load/unload that cargo, which are specified for each port and made constant for any platform, This feature is important since it changes the availability of the ports (also specified as a parameter), which means the amount of vessels admitted simultaneously, and also the availability of the vessel itself to perform another request. There is no deadline in this proposal although it is mandatory in the real problem. Such time constraint can be considering in the future.

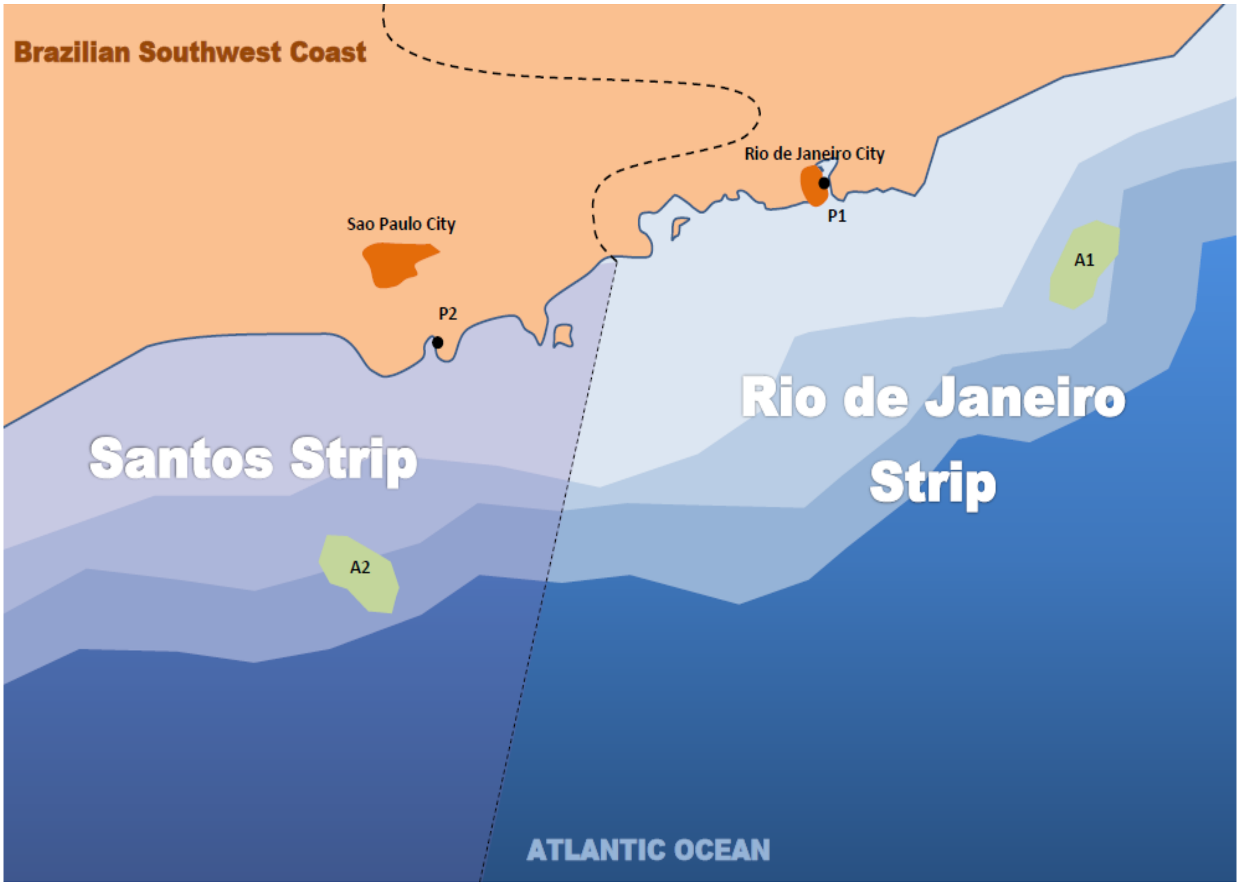

Fig. 1: Layout of the strips and position of the ports in Brazilian Coast.

Another important condition is that the vessels should be moored in any of the two regions specified in the problem: one in the Rio de Janeiro strip and another in the Santos strip. This condition is important for safety reasons and also to preserve the port and avoid crowding as well as the probability of fuel leaking.

The general problem to be solved is to take a list of requests of goods delivery and assign vessels to load cargo items in the port and deploy them in the platforms in the ocean. The use of vessels must be optimized, which means that it does not travel with a low level of cargo, it must go to as many places as its fuel allows and it goes back to either one of the mooring places, waiting areas, in the ocean with enough fuel to reach at least one of the ports. Unbalanced number of vessels in one of the mooring places can result in a waste since in the worst case one of them has to be in the platform to refuel to reach the other port, thus, it is not considered a good plan. Also, a better plan would use the smallest number of vessels possible.

Tables 1, 2 and 3 provide the distances between ports, platforms and waiting areas in this problem, as illustrated in Fig. 1.

Table 1: Distance between the target points (platforms and ports) in the Rio de Janeiro strip. *P1* is the port in Rio de Janeiro Strip and *F1-F6* are the platforms in the ocean.

	P1	F2	F3	F4	F5	F6
F1	300Km	168Km	168km	120km	260km	240km
F2	160km	-	240km	120km	168km	120km
F3	280km		-	120km	168km	260km
F4	200km			-	120km	168km
F5	160km				-	120km
F6	130km					-

Table 2: Distance between the target points (platforms and ports) in the Santos strip. *P2* is the port in Santos Strip and *G1-G4* are the platforms in the ocean.

	P2	G2	G3	G4
G1	300km	200km	120km	260km
G2	180km	-	260km	120km
G3	280km		-	200km
G4	140km			-

Table 3: Distance between the platforms (target points) and waiting areas in the Rio de Janeiro and Santos strips. *A1* and *A2* are the waiting areas of Rio de Janeiro and Santos strips, respectively. *P1* and *P2* are the ports in Rio de Janeiro and Santos, respectively.

	F1	F2	F3	F4	F5	F6	A1	A2	P1	P2
G1	468km	580Km	420km	500km	380km	520km	540km	320km	350km	300km
G2	580km	468km	380km	520km	300km	500km	540km	110km	400km	180km
G3	588km	600km	420km	560km	580km	580km	580km	400km	450km	280km
G4	600km	588km	580km	580km	420km	580km	570km	180km	420km	140km
A1	200km	40km	320km	280km	180km	80km	-	340km	120km	270km
A2	340km	380km	370km	340km	280km	300km	340km	-	270km	100km
P1	300km	160km	280km	200km	160km	130km	120km	270km	-	200km
P2	380km	290km	320km	340km	270km	300km	270km	100km	200km	-

In what follows, we describe the problem in more details, as well as the parametrization.

Problem Description

The Main Elements and Agents

Basins and Ports

In this document we will consider two basins in the Brazilian coast: *Rio de Janeiro* and *Santos.* Each one of these basins have one port in the land (port *P1* at Rio de Janeiro and port *P2* at Santos) where the loading activities of cargo items occur to support petroleum extraction in deep water. The ports can dock two ships simultaneously for loading, unloading and refueling operations. After receiving two ships all further request for docking will have to be queued. Obviously a good plan should be one where this queue is empty most of the time.

The cost for docking is R$1000/h. This cost is applied only when the vessel is moored in a port and it is computed from the time the vessel starts docking to the time it undocks.

Platforms and Ports - Target points for delivering

Both strips associated to the basins are filled with platforms in the ocean that we will call generically *F1,…,F6* those that are located in Rio de Janeiro strip and *G1,…,G4* those located at the Santos strip. These platforms frequently demand cargo items that must be delivered from the port to the requesting platform. Each group of platform is located in the proper strip connected to the respective port in the land, as shown in Fig. 1. Vessels are supposed to approach each of these target points and delivery part or all of its cargo. We do not care about the proper order of products in the vessel but only about the loading/unloading rate (1 ton per hour).

Besides the port, there are some platforms in the strips in which vessels can refuel. Not all platforms can refuel a vessel. The refueling operation of a vessel will be performed with the rate of 100 litres per hour. Only one vessel can dock at any given time in a platform; therefore, it is interesting to avoid to have other vessels in a line waiting to dock.

Vessels

Vessels are the main resource used to transport cargo items from/to ports and platforms. We are assuming that all ships have the same capacity of cargo and the same speed average (70 km/h). For simplicity we will assume that cargo items are loaded in the ports and delivered in the platforms, the target points. A set of ships (*S1, S2, S3,…, S10*) is responsible for supplying the platforms. Each ship has a limited *capacity of carrying cargo items* (100 tons) and a *limited fuel tank* (600 litres) to navigate between locations. Traveling with the specified speed average these ships will consume 1 litre of fuel each 3 km traveling fully loaded and 1 litre each 5 km if empty. We should use the former when the ship is loaded with any cargo at all (for security) and the latter only when its is empty.

Before executing any activity in a port or a platform, ships must perform a docking process. The docking or undocking process of a vessel at a port takes 1 hour, whereas at the platforms it takes 0.5 hour.

Ships can be docked at ports and platforms to (1) load and unload cargo items and (2) to be refuel, or both. The loading and unloading processes can be done either at the platforms in the ocean or at the port in the land, however, they cannot be done at the same time in a given location. Each vessel can perform the loading/unloading operation with a rate of 1 ton per hour (1 ton/h). Refuelling can be done in the port or in platforms that have a refuel system, and it can be performed while loading or unloading is running. The proper rates for refueling are: i) 100 litres per hour in a platform; ii) 100 litres in half an hour in the ports.

After completing a delivery, ships should go to the waiting areas off shore. There is one waiting area in each strip: the one in Rio de Janeiro strip (called *A1*) is located 120 km (radial distance) from the port *P1* and the one in Santos strip (called *A2*) is located 100 km from the port *P2*.

Cargo Items

Cargo items (*C1, C2,…,CN*) refer to products, food, equipment, and assembling parts that must be delivered to platforms and/or ports. They are considered as containers. They can be carried by ships from one location to another, and we disregard the order of loading and unloading in this problem. Since each cargo item has a specified weight, loading a ship is limited by the capacity of that ship. The proper weight for each cargo item is specified in the request and is considered input data for the problem.

Waiting areas in the ocean

There is one waiting area in each strip (*A1* at Rio de Janeiro and *A2* at Santos). All vessels have to be or return to these areas before staring a mission and at the end of each one. It is possible to send a vessel located initially in one waiting area to another waiting area of the other strip. However, it is important to have a balance number of vessels in each one. I other words, a good plan is the one that keeps the waiting areas as close to the ideal balance as possible. The ideal balance is 6 vessels in the Rio de Janeiro area *A1* and 4 in the Santos waiting area *A2*.

Waiting areas are close to the basin ports, 120 km from Rio and 100 km from Santos. The distance between *A1* and *A2* is 340 km. The use of waiting areas is a key issue to avoid long and unnecessary docking periods in the ports (since there is a cost associated to each docking period) and in the platforms. When parking at the waiting areas, ships must have sufficient fuel to go back to a refueling location. On the other hand, having a full tank at a waiting location is not desirable; it increases the risk of accidents that could compromise nature such as fuel linking.

In this problem we are not considering crew assignment to a vessel.

The Actions

The following actions can be performed in the domain[1]:

- **Navigate**. Navigate a ship from one location to another (port, platform or waiting area).
- **Dock a vessel**. Dock a vessel in a port or a platform in the ocean.
- **Undock a vessel**. Undock a vessel in a port or a platform in the ocean.
- **Load cargo**. Load a cargo item into the ship.
- **Unload cargo**. Unload a cargo item from the ship.
- **Refuel ship**. Refuel ship at a refueling location (port or specified platforms).

The Problem

As we said before, the general problem to be solved is to transport and deliver a list of requests of cargo considering the ports, the platforms (target points), the vessel capacity, the weights of cargo items, fuel consumption and the cost involved. Given a set of cargo items to delivery, the problems is to find a feasible plan that guarantee the delivery of the cargo items, respecting the constraints on the ship capacities. The ships should leave a waiting area, perform its mission and go back to one of the waiting areas. The objective is to minimize a series of aspects of the problem such as the total amount of fuel used, the size of the waiting queue in the ports, the umber of ships used to solve the requests, the makespan, and the docking cost.

Throughout the text we gave some information about constraints and preferences concerning the resulting plan. On of the preferences is represented by a desire of the stakeholder to keep the distribution of vessels balanced in the two waiting areas. The ideal balance was specified as 6 in the Rio waiting area and 4 in Santos waiting area. Unbalanced number of vessels in one of the mooring places can impact plans since it is possible to reach a lack of ships in one waiting area to attend the basin port. An important constraint described in the text is that each ship should return to a waiting area off shore with enough fuel to reach a refueling location (e.g. ports) but not with a full tank.

Plan Metrics

[1] The domain model can contain other supporting actions. Having only these actions is not mandatory.

The following metrics will be considered to evaluate the generated plans:

- Total amount of fuel used;
- Size of the waiting queue in the ports;
- Number of ships used to solve the requests;
- Total amount of time necessary to solve the requests, the makespan;
- Docking cost.

All the above listed metrics must be minimized.

Input Data Example

The input data for this challenge is composed by (1) the information provided in this specification and (2) a reference example of the planning problem. The following information can be found in the problem description above:

- The available ports and the cost of docking.
- The available ships with their capacities, fuel capacity, speed, and fuel consumption rates.
- The available platforms and their respective location.
- Waiting area locations in the ocean.
- Distances between ports, platforms, and waiting areas.

The planning problem example given in Table 4 is the reference for the input data. In this example, we consider six vessels in *A1* and four in *A2* as the initial position of the ships; they have all initially 400 litres of fuel in their tank. Moreover, *F5* and *G3* are the only platforms able to perform refueling, in addition to the ports.

Table 4: Example of a request to be solved.

cargo specification	loading port	delivering point	weight
C1	Rio	F1	20t
C2	Rio	F6	5t
C3	Rio	F4	15t
C4	Santos	G4	8t
C5	Rio	F2	15t
C6	Rio	F3	10t
C7	Rio	F5	25t

C8	Rio	F2	30t
C9	Santos	G2	30t
C10	Santos	G1	15t
C11	Santos	G2	20t
C12	Santos	G1	20t
C13	Santos	F3	20t
C14	Santos	F2	30t
C15	Santos	F1	40t

Using the reference planning problem describe in Table 4 we provide some modeling scenarios in the section that follows.

Scenarios

Easy

This scenario does not consider the time constraints described in the problem description, i.e., parameters such as speed, refueling rates, docking cost and docking/undocking time do not need to be considered. Here we are interested in the order constraints of a plan that solve the input problem example. The metrics will be just the total amount of fuel used.

Medium

This scenario considers all information provided in this document, including the time constraints. We consider all metrics, except the docking cost.

Hard

A hard scenario is the solution of the full problem even considering the docking cost. In addition, some of the cargo items have priority. For example, *C1*, *C2*, *C9* and *C10* must be delivered first and as quick as possible.

Modeling Language Requirements

There is no restriction on the modeling language to be used while modeling the problem. However, we encourage competitors to use declarative languages widely used in the AI Planning & Scheduling community.

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